United States Department of Agriculture | Forest Service | Northeastern Area State & Private Forestry | 180 Canfield Street Morgantown, WV 26505-3101

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John Donahue
Superintendent
USDI National Park Service
Delaware Water Gap National Recreation Area
Headquarters, River Road
Bushkill, PA 18324

Dear Mr. Donahue:

Enclosed is the biological evaluation of hemlock woolly adelgid (HWA) and elongate hemlock scale (EHS) for Childs Park, Dingmans Falls and Raymondskill Falls areas at Delaware Water Gap National Recreation Area (DWGNRA). Hemlock forests have declined over the past decade at DWGNRA due to HWA infestations, drought, EHS, and hemlock borer. The majority of the hemlock trees throughout the park are in moderate decline as a result of this complex of stressors.

HWA populations are generally low and EHS are low to moderate in these areas. The past two consecutive cold winters has helped reduce densities of these pests and hopefully a second year of normal rainfall will help hemlocks begin to recover.

Hemlock trees can typically tolerate a moderate infestation of EHS with little or no visible damage. Favorable conditions for building EHS populations are stressed trees and mild winters. At this time, there no suitable treatment options available to control EHS in the forest environment. Indirect control might best be accomplished by reducing other stress factors to the extent possible. As such, individual high value hemlocks should be closely inspected for HWA infestations and treated when necessary.

To control HWA, we recommend using imidacloprid formulated for use as a soil injection, soil drench or stem injection. Treatment timing for these application methods is spring or fall for soil treatments and fall for stem injections.

Please contact Brad Onken (304-285-1546) if you have any questions concerning this biological evaluation or other related questions.

Sincerely,

JOHN W. HAZEL
Field Representative MFO

Enclosure

Cc: Richard Evans, DWG
Wayne Millington, USDI NPS
Noel Schneeberger, AO
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Biological Evaluation of Hemlock Woolly Adelgid and Elongate Hemlock Scale at Delaware Water Gap National Recreation Area, Milford, Pennsylvania

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ABSTRACT

On March 9, 2004, personnel from the USDA Forest Service, Northeastern Area, Forest Health Protection, Morgantown Field Office, conducted a survey to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae*, and elongate hemlock scale (EHS), *Fiorinia externa*, population densities at Delaware Water Gap National Recreation Area (DWGNRA). The purpose of the survey was to assess the need for treatment in the Childs Park, Dingmans Falls, and Raymondskill Falls areas. Current populations of both insect pests are generally low on most trees in these areas as a result of two consecutive years of cold winter temperatures and declining tree health conditions. HWA populations in the Childs Park area have the greatest potential to rebound this year. Control of HWA on high value hemlock trees in the Childs Park area is recommended to prevent further decline of tree health.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that generally feed on plant sap. The family is divided into two genera: *Adelges* and *Pineus*. The members of this family feed exclusively on conifers. There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator and parasite complex associated with these native adelgids.

Native to Asia, the hemlock woolly adelgid (*Adelges tsugae)*, is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999) both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). The HWA is currently established in 16 Eastern States from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1999, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at

SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). In New Jersey less than 13 percent of stands surveyed in 1991 remain healthy. Twelve years after initial HWA infestations, tree mortality has reached more than 90% in some New Jersey hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock; each adult adelgid can produce 50 to 300 eggs in her lifetime (McClure 1989, 1995). The hemlock woolly adelgid also has a winged form that is produced by the spring generation. This form must complete part of its life cycle on spruce. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent (McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and quantity of the food source, which is associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999). Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all life stages of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs and are committed to that feeding site throughout the remainder of its development. The stylet bundle is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001). Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Natural enemies capable of maintaining low-level HWA populations are nonexistent in eastern North America (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to be resistant because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002). In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing

extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

SCALE INSECTS

There are several scale insects that affect hemlocks in the eastern United States. The more common ones belong to the family *Diaspididae*, or armored scales. Armored scales form a protective cover that is unattached to the body. The hemlock scale, *Abgrallaspis ithacae,* is native to the United States and is probably present throughout the East. *A. ithacae* is generally not a significant pest (Johnson and Lyon 1988). The hemlock scale has also been reported on fir (*Abies* species) and spruce (*Picea* species) (Drooz 1989). Two exotic scales that attack the eastern and Carolina hemlock are the elongate hemlock scale, *Fiorinia externa*, and the shortneedle evergreen scale (a circular hemlock scale), *Nuculaspis tsugae* (Johnson and Lyon 1988, McClure 2002a). Native to Japan, the shortneedle evergreen scale and the elongate hemlock scale were first reported in the United States, in 1910 and 1908, respectively. The shortneedle evergreen scale is now known to occur in Connecticut, Maryland, New Jersey, Rhode Island, and New York (McClure 2002a), and its hosts other than hemlock include fir, cedar (*Cedrus* species), spruce and yew (*Taxus* species) (Drooz 1989). The EHS has been found in the District of Columbia and in nine states from Virginia to southern New England and west to Ohio (McClure 2002b). The EHS is known to occur on species of spruce, fir, yew and hemlock (Drooz 1989). Spruce and fir tend to be even more susceptible than hemlock, although it has not yet spread into the natural ranges of these other native conifers. Circular hemlock scale is far less abundant and generally out competed by the elongate hemlock scale (McClure 2002a).

The EHS completes two generations each year in the Southern and Mid-Atlantic States, but usually only one in the Northeast. Its life stages are broadly overlapping everywhere, and crawlers can be found throughout the spring and summer. Crawlers are the only stage capable of dispersing and establishing new infestations. Dispersal between trees is primarily by wind and birds. Females have three stages of development after the egg stage, while males have five. During the first and second instar stages, both sexes settle beneath the thin waxy cuticle on the lower surface of the youngest hemlock needles and begin to feed. While in these stages, both sexes secrete a cover around itself as it grows. After the first and second nymphal instar stages, the female then molts into the adult feeding stage, while the male molts into a non-feeding prepupa and spins a cocoon, where it pupates before it emerges as an adult. The adult male mates with the female and dies soon thereafter without feeding. The adult female lays about 20 eggs within her cover. The EHS usually overwinters, either as an egg or as an inseminated adult female. When the crawlers hatch, they exit through a small opening at the posterior end of the cover (McClure 2002b).

The EHS attacks the underside of the hemlock needles by removing fluids from the mesophyll cells through piercing and sucking mouthparts. Scale populations build slowly on healthy trees, but much more quickly on stressed ones. Feeding by HWA has been shown to affect nutrient dynamics in hemlock stands (Jenkins et al. 1999) and this could feasibly reduce tree vigor sufficiently to allow scale insects such as EHS to become

established and explode in population size (Danoff-Burg and Bird 2002). Mixed infestations of EHS and HWA can greatly hasten hemlock decline. Feeding by EHS causes foliage to turn yellow and drop prematurely. Dieback of major limbs, which usually progresses from the bottom of the tree upwards, usually occurs after scale density reaches about 10 individuals per needle. Trees often die within the next 10 years, but some survive longer in a severely weakened condition with only a sparse amount of foliage at the very top of the crown. These weakened trees have very little chance of recovery and often fall victim to secondary pests, such as hemlock borer and *Armillaria* root disease or readily broken and thrown by wind (McClure 2002b).

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000).

Hemlock trees contribute to the ecological, aesthetic and recreational values of Delaware Water Gap NRA. Eastern hemlock is an important component of the forest, covering approximately 2, 800 acres (about 5%) of DWGNRA (Myers and Irish 1981, Young et al. 1998). Many scenic waterfalls are associated with hemlock stands at DWGNRA. Popular recreational activities in these areas of the recreation area include hiking, trout fishing, bird watching, sight seeing, and picnicking.

Important hemlock forests in the recreation area are located in the following areas:

Dingmans Creek (trails and visitor center)
Adams Creek (state designated "exceptional value" trout streams)
Toms Creek (state designated "exceptional value" trout streams)
Raymondskill Creek ((trails)
Hornbecks Creek (important to the Pocono Environmental Education Center)
Tumbling Waters (important to the Pocono Environmental Education Center)
Van Campens Brook (a "blue-ribbon "trout stream and picnic area)
Buttermilk Falls
Copper Mine ravine
Dunnfield Creek

Recent studies conducted in DWGNRA have documented many distinctive characteristics of hemlock forests and ecosystems (Evans 2000). At Adams Creek and VanCampens Brook, 316 species of plants have been documented (Battles et al. 2000). Hemlock ravines in DWGNRA support more than 15 species of amphibians and more than 12 species of small mammals; relatively high numbers when compared to many other forest types in the region (Sciascia and Pehek 1995). At least 152 species of ground invertebrates occur in hemlock forests at the recreation area (Schweitzer 1994).

Small streams in hemlock forests are three times more likely to support native brook trout populations than similar streams in hardwood forests in the Delaware Water Gap NRA (Snyder et al. 1998). Hemlock forest streams typically support about 65 species of aquatic insects, compared to about 35 species in hardwood forest streams. There are about 15 species of aquatic insects that seem to occur almost exclusively in hemlock forest streams in the DWGNRA (Snyder et al. 1998).

HWA HISTORY AND OTHER STRESSORS AFFECTING HEMLOCK HEALTH CONDITIONS AT DELAWARE WATER GAP NATIONAL RECREATION AREA

HWA was first noticed within the DWGNRA in 1989 at Dunnfield Creek (New Jersey) and Mount Minsi (Pennsylvania) (Millington 1989). Since 1989, HWA has spread throughout the recreation area (Evans 2002). Donkey's Corner ravine was heavily infested with HWA by 1992. In 1995, HWA was detected at 30 of 58 (52%) surveyed sites located throughout DWGNRA. By 1999, HWA was found at all (100%) of the same 58 surveyed sites. In 1999, more than 50 percent of the hemlock trees evaluated at Mount Minsi, and three-quarters of the hemlock trees at Dunnfield Creek and Donkeys Corners were either dead or defoliated (Evans 2000).

Other stresses include elongate hemlock scale, hemlock borer beetle (*Melanophila fulvoguttata*) and droughts of recent years. The presence of elongate hemlock scale at DWGNRA was first noticed a couple of years ago. Hemlock borer beetles usually attack only severely stressed hemlock trees. With the HWA infestations and drought, hemlock trees have become stressed and vulnerable to attack by the hemlock borer beetles and EHS. Hemlock borer beetles can become so abundant during these outbreaks that they attack and severely injure or even kill otherwise healthy hemlock trees (Evans 2000). Hemlock borer beetle damage is evident in the Raymondskill Creek, Conashaugh Creek, Dry Brook, Adams Creek, Dingmans Creek, Hornbecks Creek, and Spackmans Creek areas.

In 1993, DWGNRA staff established individually marked hemlock trees in 81 permanent plots distributed among seven sites around the recreation area to assess hemlock tree health and mortality. From 1993 to 2002, crown transparency (relative amount of light that can pass through the tree crown) increased from 15 % to 35%. Crown dieback increased from about 5 % to over 20%. Vigor rating data collected in 2002 indicate that 25 % of the hemlock trees in the monitoring plots were either dead or in severe decline, 48% were in light to moderate decline, and 27% were healthy. These plots were originally distributed in such a way as to be representative of each hemlock stand they were located in, but not necessarily of the entire recreation area (Evans 2003).

From 2000 to 2003, DWGNRA has released 65,700 *Sasajiscymnus tsugae* (formally *Pseudoscymnus tsugae*) predatory beetles for HWA biocontrol at twelve sites within the recreation area. The twelve sites are located in the Lower Adams Creek, Upper VanCampens Brook, Lower Dingmans Creek, Upper Hornbecks Creek, Upper Buttermilk Falls, Lower Donkeys Corner ravine, Old Mine Road (2 sites), Upper Glen

(VanCampens Brook), Hemlock Road, Camp Ken-Etiwa-Pec, and Lower White Brook areas.

HWA samples collected in March 2003 indicated over 50% mortality of over-wintering HWA, most likely a result of relatively severe temperatures during the winter of 2002-2003. Samples collected in March 2004, averaged over 80% winter mortality.

Current estimates of hemlock conditions within the DWGNRA indicate that only 20 percent of the hemlocks are healthy, 60 percent are at various stages of decline, and about 20 percent are dead (Evans 2003).

METHODS

Live hemlock trees (> 6" dbh) were randomly selected for inspection within the survey areas. An assessment of tree vigor, branch tip dieback, crown position, dbh, and HWA and EHS population densities was conducted of each tree. Branch samples were collected and returned to the lab to evaluate viability of HWA populations and degree of winter mortality.

HWA and EHS infestation levels were designated as heavy, moderate, light or none based on the criteria listed below:

HWA – Based on the percentage of tips with adelgid present per 30 centimeters of hemlock twig length: Heavy (H) = >50% infested
Moderate (M) = 50% to 25% infested
Light (L) = <25% infested
None (N) = 0% infested

EHS – Visual estimates based on scale presence on 30 centimeters length of hemlock branch: Heavy = >1/needle on average
Moderate = 1/needle on average
Light = <1/needle on average
None = 0% infested

Vigor indicates the health of the tree crown based on the rating below:

Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present
Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown
Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown
Moderate-Severe Decline (MS) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 51-75% of crown

Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

RESULTS

The survey areas are represented in Figure 1. The results of the survey are summarized in Table 1. Hemlock woolly adelgid infestations are light to none at the Dingmans Falls and Raymondskill Falls areas and are generally light to moderate at the Childs Park area. HWA winter mortality at Delaware Water Gap NRA averaged over 80 percent.

Hemlock trees in all the surveys area at DWGNRA are generally in moderate decline.

Elongate hemlock scale infestations are generally light to none at the Dingmans Falls and Raymondskill Falls areas and light to moderate at the Childs Park Area.

Figure 1. Hemlock woolly adelgid and elongate scale survey locations at Delaware Water Gap NRA, Milford, PA – Child Park, Dingmans Falls, and Raymondskill Falls areas – Spring 2004.

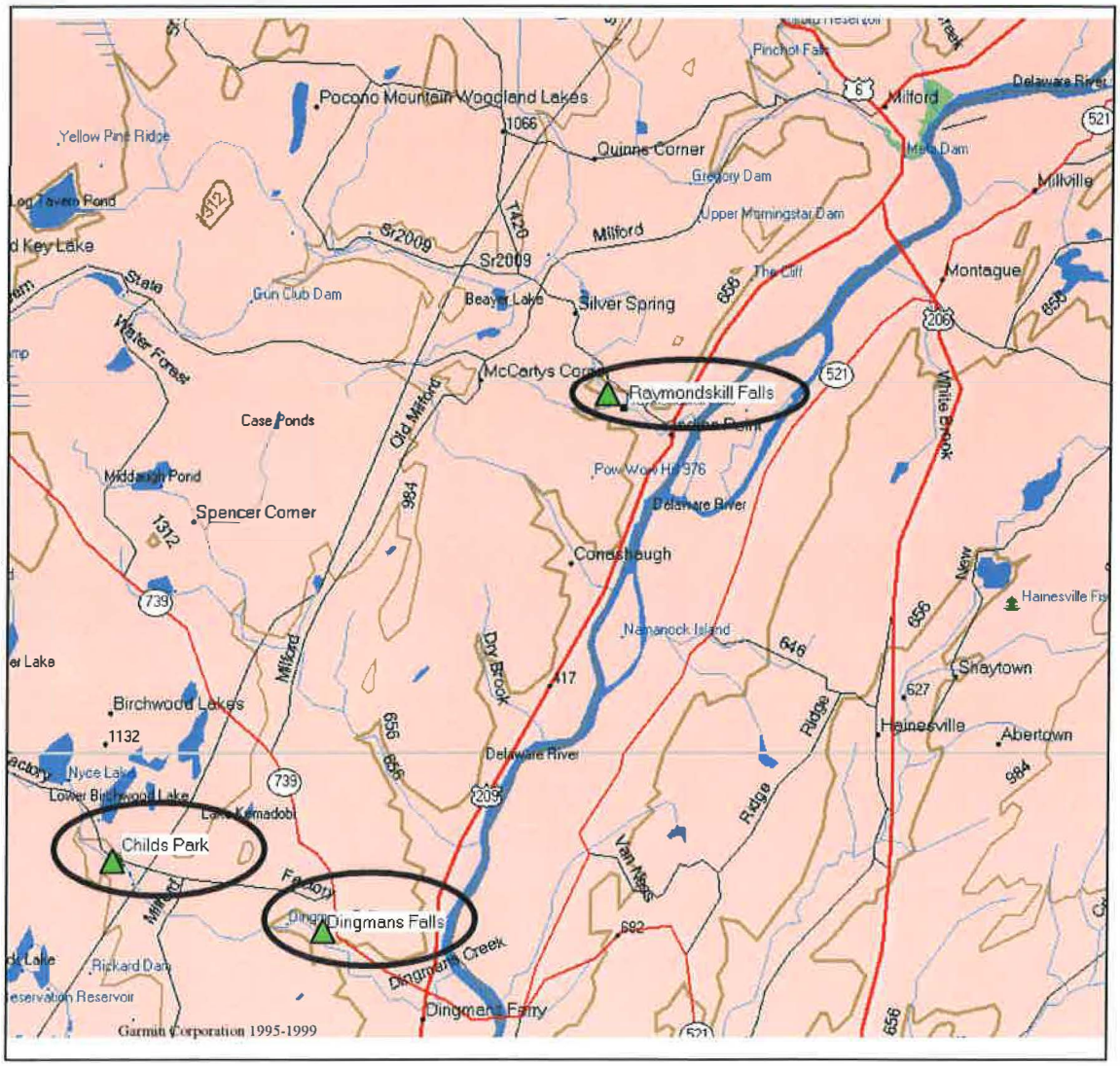

Table 1. *Summary of the hemlock woolly adelgid and elongate hemlock scale survey results for the Childs Park, Dingmans Falls, and Raymondskill Falls areas at Delaware Water Gap NRA, March 2004.*

TREE #	LOCATION	DBH[1]	CROWN POSITION[2]	HWA INFEST LEVEL[3]	ELONGATE SCALE INFEST LEVEL[4]	DEAD TIP %[5]	VIGOR[6]
1	Childs Park	24	CD	LIGHT	LIGHT	7	M
2	Childs Park	12	I	LIGHT	LIGHT	13	M
3	Childs Park	12	CD	HEAVY	LIGHT	11	MS
4	Childs Park	8	I	MODERATE	MODERATE	18	M
5	Childs Park	14	CD	LIGHT	LIGHT	23	M
6	Childs Park	24	D	NONE	LIGHT	0	LD
7	Childs Park	16	CD	NONE	LIGHT	19	LD
8	Childs Park	12	I	NONE	LIGHT	8	LD
9	Childs Park	18	CD	NONE	LIGHT	43	LD
10	Childs Park	14	CD	LIGHT	LIGHT	30	LD
11	Childs Park	16	CD	NONE	MODERATE	1	LD
12	Childs Park	20	CD	NONE	HEAVY	7	LD
13	Childs Park	24	CD	LIGHT	MODERATE	26	H
14	Childs Park	12	CD	LIGHT	LIGHT	3	M
15	Childs Park	28	CD	NONE	LIGHT	8	LD
16	Childs Park	12	CD	NONE	MODERATE	10	MS
17	Childs Park	16	CD	NONE	LIGHT	7	M
18	Childs Park	16	CD	HEAVY	LIGHT	3	M
19	Childs Park	22	CD	HEAVY	LIGHT	0	LD
20	Childs Park	14	CD	MODERATE	LIGHT	26	LD
21	Childs Park	20	CD	NONE	LIGHT	21	M
22	Childs Park	10	I	MODERATE	LIGHT	18	S
23	Childs Park	12	I	LIGHT	LIGHT	23	MS
24	Childs Park	14	CD	NONE	LIGHT	16	M
25	Childs Park	14	CD	NONE	LIGHT	19	M
26	Childs Park	16	CD	LIGHT	LIGHT	22	M
27	Childs Park	12	CD	NONE	LIGHT	4	M
28	Childs Park	10	CD	LIGHT	LIGHT	4	S
29	Childs Park	14	CD	LIGHT	LIGHT	65	M
30	Childs Park	14	CD	MODERATE	LIGHT	46	M
31	Childs Park	10	CD	LIGHT	LIGHT	5	LD
32	Childs Park	10	CD	LIGHT	LIGHT	28	M
33	Childs Park	14	CD	LIGHT	LIGHT	4	M
34	Childs Park	12	CD	NONE	LIGHT	0	M
35	Childs Park	18	CD	LIGHT	LIGHT	10	M
36	Childs Park	24	D	NONE	LIGHT	3	LD
37	Childs Park	18	D	NONE	LIGHT	23	LD
38	Childs Park	12	CD	LIGHT	LIGHT	15	M

Table 1. *Continued*

TREE #	LOCATION	DBH[1]	CROWN POSITION[2]	HWA INFEST LEVEL[3]	ELONGATE SCALE INFEST LEVEL[4]	DEAD TIP %[5]	VIGOR[6]
39	Childs Park	14	CD	LIGHT	LIGHT	13	H
40	Childs Park	12	I	NONE	LIGHT	2	M
41	Childs Park	16	CD	NONE	LIGHT	7	M
42	Childs Park	14	CD	NONE	LIGHT	16	M
43	Childs Park	24	D	NONE	LIGHT	3	M
44	Childs Park	10	S	LIGHT	LIGHT	3	M
45	Childs Park	14	CD	NONE	LIGHT	15	M
46	Childs Park	12	I	LIGHT	LIGHT	6	M
47	Childs Park	34	D	LIGHT	LIGHT	52	M
48	Childs Park	30	D	NONE	LIGHT	2	M
49	Childs Park	18	CD	NONE	LIGHT	11	LD
50	Childs Park	14	CD	NONE	LIGHT	9	MS
1	Dingmans Falls	16	CD	LIGHT	LIGHT	4	LD
2	Dingmans Falls	24	D	NONE	LIGHT	5	LD
3	Dingmans Falls	14	CD	NONE	LIGHT	4	M
4	Dingmans Falls	20	CD	NONE	LIGHT	3	M
5	Dingmans Falls	16	CD	NONE	LIGHT	9	LD
6	Dingmans Falls	20	CD	NONE	LIGHT	0	SD
7	Dingmans Falls	18	CD	NONE	LIGHT	7	LD
8	Dingmans Falls	14	CD	LIGHT	NONE	5	M
9	Dingmans Falls	10	I	NONE	NONE	82	M
10	Dingmans Falls	16	CD	NONE	NONE	4	M
11	Dingmans Falls	14	CD	LIGHT	NONE	1	M
12	Dingmans Falls	28	D	MODERATE	NONE	6	M
13	Dingmans Falls	16	CD	NONE	LIGHT	7	M
14	Dingmans Falls	16	CD	NONE	LIGHT	16	M
15	Dingmans Falls	24	CD	LIGHT	LIGHT	3	M
16	Dingmans Falls	20	CD	MODERATE	NONE	1	M
17	Dingmans Falls	24	CD	NONE	NONE	0	M

Table 1. *Continued*

TREE #	LOCATION	DBH[1]	CROWN POSITION[2]	HWA INFEST LEVEL[3]	ELONGATE SCALE INFEST LEVEL[4]	DEAD TIP %[5]	VIGOR[6]
18	Dingmans Falls	16	CD	NONE	NONE	14	M
19	Dingmans Falls	18	CD	LIGHT	LIGHT	12	M
20	Dingmans Falls	14	CD	LIGHT	NONE	4	MS
21	Dingmans Falls	10	I	LIGHT	LIGHT	34	MS
22	Dingmans Falls	18	CD	LIGHT	NONE	4	M
23	Dingmans Falls	12	I	NONE	NONE	32	M
24	Dingmans Falls	14	CD	NONE	NONE	5	M
25	Dingmans Falls	14	CD	NONE	NONE	0	M
1	Raymondskill Falls	14	CD	NONE	LIGHT	16	M
2	Raymondskill Falls	12	CD	NONE	LIGHT	23	M
3	Raymondskill Falls	10	I	NONE	LIGHT	14	M
4	Raymondskill Falls	14	CD	NONE	NONE	32	M
5	Raymondskill Falls	12	I	NONE	LIGHT	20	M
6	Raymondskill Falls	20	CD	LIGHT	LIGHT	6	M
7	Raymondskill Falls	16	CD	NONE	LIGHT	28	M
8	Raymondskill Falls	14	CD	NONE	LIGHT	17	M
9	Raymondskill Falls	10	I	HEAVY	LIGHT	14	MS
10	Raymondskill Falls	14	CD	LIGHT	LIGHT	10	M
11	Raymondskill Falls	16	CD	LIGHT	LIGHT	11	M
12	Raymondskill Falls	20	CD	NONE	LIGHT	9	M
13	Raymondskill Falls	16	CD	LIGHT	LIGHT	7	MS
14	Raymondskill Falls	12	I	NONE	LIGHT	13	M
15	Raymondskill Falls	10	S	LIGHT	NONE	43	M
16	Raymondskill Falls	16	CD	NONE	NONE	10	M

Table 1. *Continued*

TREE #	LOCATION	DBH[1]	CROWN POSITION[2]	HWA INFEST LEVEL[3]	ELONGATE SCALE INFEST LEVEL[4]	DEAD TIP %[5]	VIGOR[6]
17	Raymondskill Falls	14	CD	LIGHT	NONE	9	M
18	Raymondskill Falls	10	CD	LIGHT	NONE	2	M
19	Raymondskill Falls	10	I	NONE	NONE	10	M
20	Raymondskill Falls	14	CD	LIGHT	NONE	3	M
21	Raymondskill Falls	12	CD	NONE	NONE	4	M
22	Raymondskill Falls	14	D	NONE	NONE	0	LD
23	Raymondskill Falls	12	CD	NONE	NONE	30	LD
24	Raymondskill Falls	12	I	NONE	NONE	21	M
25	Raymondskill Falls	16	CD	NONE	NONE	16	LD

[1]-DBH= estimated tree diameter at breast height to nearest inch

[2]-Crown position: D=dominate, CD=codominate, I=intermediate, S=suppressed, OG=open grown

[3]-Percentage of tips with adelgid present per 30 centimeters (cm) of hemlock twig length: Heavy = (>50% infested), Moderate = (50% to 25% infested), Light = (<25% infested), None = (0% infested)

[4]-Scale presence based on visual estimates from 30 cm length of hemlock branch: HEAVY = (>1/needle on average), MODERATE = (1/needle on average), LIGHT = (<1/needle on average), NONE = (0% infested)

[5]-Precentage of dead tips per 30 centimeters of hemlock twig length

[6]- Vigor = Tree crown health:

Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present

Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown

Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown

Moderate-Severe Decline (MS) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 51-75% of crown

Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

DISCUSSION

Over the past decade, hemlock forests at DWGNRA continue to decline as a result of HWA infestations and other stressors, such as drought, EHS and hemlock borer. The majority of hemlock trees in all the surveyed areas are in moderate decline.

HWA population densities are generally low in the survey areas, with the exception of Childs Park where densities are light to moderate. Lower adelgid populations often occur on declining trees as they offer lower food quantity and nutritional quality. Two consecutive years of cold winter temperatures also contributed to high HWA winter mortality. However, with the unusually high precipitation in 2003, stress on hemlock trees should be alleviated some, and potentially allow for a flush of new growth during the 2004 growing season (Evans 2003). If this is the case, HWA has the ability to quickly rebound.

EHS population densities are generally low to none in the survey areas, with the exception of the Childs Park area where densities are light to moderate. Healthy hemlocks can typically sustain moderate densities of EHS but are often overwhelmed when attacked trees are already stressed. Population densities fluctuate periodically depending on the severity of winters, but often rebound following such events.

Consequently, impacts to hemlock resources throughout DWGNRA may continue to increase and bring about major ecosystem transformations. Should this occur, there will be the loss of valued biodiversity, and recreational and aesthetic resources associated with hemlock ecosystems, along with the challenges of managing hazard trees as a result of dead and dying hemlocks in high-use areas.

Management Considerations

There are no native natural enemies capable of controlling HWA in Eastern North America. As such, the USDA Forest Service has initiated a classical biological control program to introduce and establish a complex of natural enemies throughout the infested region. Predators such as *Sasajiscymnus (= Pseudoscymnus) tsugae, Laricobius nigrinus and Scymnus sinuandodulus* are currently being released and established throughout the infested region (including the DWGNRA) and foreign exploration and the evaluation of potential new predators is ongoing. These efforts are long term strategies however and it will take a number of years before any measurable control can be established. In the interim, resource managers may need to consider the use of chemical control to protect individual specimen trees of high value or for genetic preservation.

Management options for preserving hemlock stands at DWGNRA are limited by the biology and feeding behavior of HWA and EHS, pest population densities, site conditions

(i.e. proximity to streams), and limited chemical and application technology currently available.

Aerial spraying using horticultural oil or insecticidal soap is not an effective treatment because it fails to provide the needed "saturation" coverage necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits (Evans 2000). Application of insecticides using ground spraying equipment is effective at controlling HWA and EHS, but is limited to areas accessible to heavy hydraulic spray equipment and areas where over spray or run off would not contaminate streams or ponds. There are no known pheromones for either HWA or EHS. Successful establishment of predators of HWA such as *Sasajiscymnus tsugae* (*S.t*) (formerly *Pseudoscymnus tsugae*) requires a viable and healthy population of adelgids, which ironically is linked to healthy hemlocks. Soil injections using systemic insecticides such as imidacloprid has been proven to be effective at controlling HWA when trees are in severe decline but is not effective at controlling EHS. Tree injection of imidacloprid has had mixed results in controlling HWA and should be limited to trees that are not severely stressed.

Systemic Insecticides

Several types of systemic insecticides can be injected (e.g. imidacloprid, bidrin or Metasystox-R®) or implanted (e.g. acephate) into hemlock trees, and another (Merit®) can be applied as a soil drench or injected into to the soil around hemlock trees. These insecticides are absorbed and transported by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992a). Soil injection can cause minor leaching of the insecticide into the soil profile and groundwater (McAvoy et al. 2002). A study in Virginia by McAvoy and others reported that lake and spring water samples tested near injection sites found trace amounts (<0.5 to 3.6 ppb) of imidacloprid in a few of the samples collected. Although these amounts are well below the LC50 (lethal concentration necessary to result in 50% mortality) level for trout, daphnia and algae (211,000 85,000 and 10,000 ppb, respectively), it would be prudent not to use soil injections in close proximity to sources of water where this is a concern.

Formulations of imidacloprid for use in tree injection systems include Pointer®, IMA-jet® and Imicide® and are also labeled for control of adelgids. Although imidacloprid products are labeled for the control of scale pests, it has not proven to be effective on EHS. Acephate is also labeled to control adelgids and scale pests and is available as a trunk implant under the trade name ACECAP®. However no efficacy tests are available for the EHS.

Imidacloprid

Imidacloprid is a relatively new insecticide in the family of chemicals called neonicotinoids (Felsot 2001) in the chloronicotinyl subgroup (USDA Animal and Plant Health Inspection Service 2002). It has a mode of action similar to that of the botanical

product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the nicotinergic receptor sites in the postsynaptic membrane of the insect nerve (USDA Animal and Plant Health Inspection Service 2002), mimicking the action of acetylcholine, and thereby heightening, then blocking, the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). Because imidacloprid is slowly degraded in the insect, it causes substantial disorder within the nervous system, leading in most cases to death (Mullins 1993, Smith and Krischik 1999).

Imidacloprid is considered to have low to moderate mammalian toxicity (Mullins 1993), largely because it does not bind nerve receptors in mammals sufficiently to trigger nervous activity (Felsot 2001). The selective toxicity of imidacloprid is perhaps best illustrated by its use in flea treatments approved for cats and dogs. Advantage® is applied directly to the animal's skin; this preparation carries very little, if any, risk to the animal or to the people, including children, who may handle the animal (USDA Animal and Plant Health Inspection Service 2002). Chronic (repeated dose) toxicity studies have demonstrated that imidacloprid is not carcinogenic and is not mutagenic and demonstrates no primary reproductive toxicity (Mullins 1993). In studies of metabolic fate in rats, imidacloprid was rapidly absorbed and eliminated in the excreta (90 percent of the dose within 24 hours) with little bioaccumulation (0.5 percent of the dose after 48 hours) and no biologically significant differences occurring between sexes, dose level, and route of administration (USDA Animal and Plant Health Inspection Service 2002). Imidacloprid is an insecticide exhibiting both systemic and contact activity. The spectrum of activity primarily includes sucking insects (aphids, whiteflies, leaf and plant hoppers, thrips, plant bugs, and scales), many Coleopteran species, and selected species of Diptera and Lepidoptera. Although scales are listed, it has not been consistently proven to be effective for EHS control. Activity has also been demonstrated for ants (Hymenoptera); termites (Isoptera); and cockroaches, grasshoppers, and crickets (Orthoptera). No activity has been demonstrated against nematodes or spider mites (Mullins 1993). In spider mites, imidacloprid has been demonstrated to cause an egg-laying enhancement (James and Price 2002). Since spider mites can be a problem in hemlock, any imidacloprid-treated tree should be carefully monitored for increases in mite populations.

Little is known about the biotransformation and bioactivity of the metabolites of imidacloprid in hemlock. What is known is that trunk-injected imidacloprid generally requires a week or longer to provide adelgid control, with protection lasting for up to 2 years (Tater et al. 1998, Silcox 2002). The soil injection or soil drench methods of imidacloprid treatments take several months for translocation to occur, but provides better consistency in treatment efficacy when compared to stem injections.

RECOMMENDATIONS

Systemic insecticide treatments using imidacloprid are recommended for HWA control on high valued infested hemlock trees within the park, and in particular the Childs Park area. Hemlocks at the Childs Park area are generally in moderate decline with generally light to moderate EHS and HWA population densities. Where possible, soil treatments

are preferred over stem injections as they offer more consistency in treatment efficacy. Merit® applied at 0.75 ounces of a.i. per 30 cumulative inches of trunk diameter (dbh) is recommended for the soil injections, and treatment timing should be in the spring or fall. The insecticide recommended for stem injections is IMA-jet® at 5% active ingredient with the number of application sites on the tree determined by dbh. Criteria for number of application sites is as follows: 4 application sites for 6-16 inches dbh, then add one additional application site for each additional 4 inches of dbh. Treatment timing for stem injections is in the fall.

At Dingmans Falls and Raymondskill Falls areas, HWA populations are generally low and EHS is low to moderate. There are few treatment options proven to control EHS in the forest environment at this time and consequently, no treatment is recommended. Existing chemical options have a high potential for non-target effects and land managers must balance the risk of these effects with the potential benefits that come with the control of the EHS

Two consecutive cold winters (2002-03 and 2003-04) in the region has helped provide some relief by reducing densities of both pests. With continued adequate rainfall, some hemlocks should begin to recover which will further help mitigate stress caused by EHS. However, as new growth resumes, HWA populations often rebound and therefore continued monitoring of tree health and pest conditions on highly valued hemlocks throughout the park is recommended.

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